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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 4 : G02F 1/137

A1

(11) International Publication Number: WO 88/08552

(43) International Publication Date: 3 November 1988 (03.11.88)

(21) International Application Number: PCT/GB88/00320

(22) International Filing Date: 25 April 1988 (25.04.88)

(31) Priority Application Number: 8709659

(32) Priority Date: 23 April 1987 (23.04.87)

(33) Priority Country: GB

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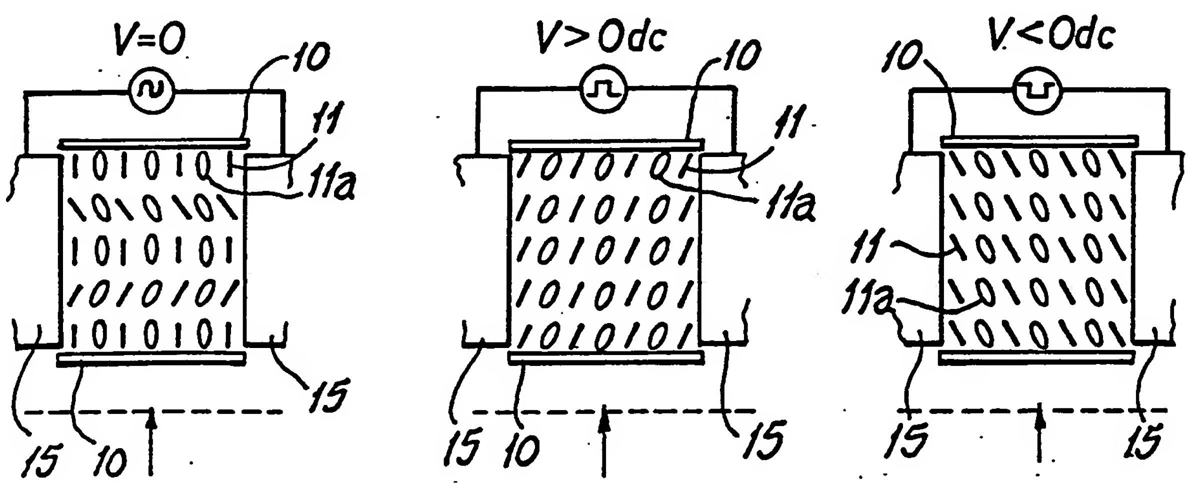
(81) Designated States: AT, AT (European patent), AU, BB, BE (European patent), BG, BJ (OAPI patent), BR, CF (OAPI patent), CG (OAPI patent), CH, CH (European patent), CM (OAPI patent), DE, DE (European patent), DK, FI, FR (European patent), GA (OAPI patent), GB, GB (European patent), HU, IT (European patent), JP, KP, KR, LK, LU, LU (European patent), MC, MG, ML (OAPI patent), MR (OAPI patent), MW, NL, NL (European patent), NO, RO, SD, SE, SE (European patent), SN (OAPI patent), SU, TD (OAPI patent), TG (OAPI patent), US.

Published
With international search report.
Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.

(54) Title: FERROELECTRIC LIQUID CRYSTAL DEVICES



(57) Abstract

A liquid crystal device which may be operated to transmit, reflect, absorb or absorb and re-emit light, incorporating a ferroelectric liquid crystal phase as exhibited by low molar mass or polymeric compounds or mixtures thereof. The material may constitute or contain a dichroic or pleochroic dye or a fluorescent or luminescent dye. The application of an electric field causes molecular reorientation within the material and/or the dye to enable control of the passage of light into and through the device. Polarisers and additional colour filtration may be incorporated, and the device may be operated to produce monochromic or polychromic images of varying intensities for small or large area displays operating at normal ambient or other temperature levels.

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FERROELECTRIC LIQUID CRYSTAL DEVICES

THIS INVENTION is concerned with light transmission or reflection systems using liquid crystal materials.

Liquid crystal "shutters" which can be switched electrically selectively to transmit, reflect or absorb light may have many different applications. Present day watch and calculator displays are common examples of the use of such shutters (see G.J. Sprokel (Ed) in "The Physics and Chemistry of Liquid Crystal Devices", Plenum Press, 1980). In these devices transparent electrodes are used to apply fields across the liquid crystals to change their orientation in the region between these electrodes. This change in orientation produces a change in the optical appearance which then is in contrast with the unswitched regions adjacent to the elctrodes. The electrodes are normally deposited on a glass or plastics substrate, two of which, with the liquid crystal sandwiched between, form the device or shutter. The most common form of such a device is known as the Twisted Nematic Display in which polarizers and analysers are used to view the optical changes. In a further application to be described below, by placing two such devices before the eyes and switching them alternately, a three dimensional effect is created for the

user. The principles of such a device are outlined in British patent no. 1448520.

Such devices as the above are known incorporating liquid crystal materials in the "twisted" Nematic phase. These devices are known to be relatively slow and cannot be switched from one state to another any faster than about 10 milliseconds.

An object of the present invention is to provide a liquid crystal "shutter" which may be switched using conveniently low voltages in a period less than 1 millisecond. Under suitable conditions this period may be reduced to something like 10 micro-seconds.

According to the present invention there is provided a liquid crystal device which may be operated to transmit, reflect or absorb light, incorporating a ferro-electric liquid crystal phase as exhibited by low molar mass or polymeric compounds or mixtures thereof.

An embodiment of the invention will now be decribed, by way of example only, with reference to the accompanying diagrams in which:-

Fig. 1 is a cross-section through a liquid crystal device made in accordance with the invention;

Fig. 2 is a diagrammatic representation showing the molecular order of the liquid crystal materials in a non-light transmitting state; and

Fig. 3 is a similar view in the transmitting state.

Figs. 4, 4a and 4b are diagrammatic representations of an absorption mode single polariser guest-host ferroelectric device made in accordance with the invention;

Fig. 5 is a graph of the light transmission characteristics of the absorption mode single polariser device shown in Fig. 4;

Figs. 6a and 6b are diagrammatic representations of an absorption mode double-guest-host ferroelectric device without polarisers, made in accordance with the invention.

Figs. 7a and 7b are diagrammatic representations of a fluorescent mode single polariser guest-host ferroelectric device made in accordance with the invention;

Fig. 8 is a graph of the light transmission characteristics of the fluorescent mode single polariser device shown in Fig. 7;

Figs. 9a and 9b are diagrammatic representations of a fluorescent mode guest-host ferroelectric device without polarisers made in accordance with the invention;

Figs. 10a and 10b are diagrammatic representations of a combined absorption and fluorescent mode double guest-host ferroelectric device without polarisers made in accordance with the invention;

and Figs. 11a to 11c are diagrammatic representations of a fluorescent or absorption mode guest-host ferroelectric device with optional polariser made in accordance with the invention.

A fast optical shutter is provided using materials exhibiting ferroelectric liquid crystal phases such as the Chiral Smectic C phase. If driven by pulsed DC signals using a field as low as 20 volts per micron or less the speed at which the device changes from a light transmitting to a light absorbing state, or from an absorbing to a light emitting state as will be described, is less than 1 millisecond, and so a shutter of this kind may be driven

using a simple battery pack.

This kind of device may then be used to display visual information in alpha-numeric, dot matrix, meander pattern or other forms suitable for applications ranging from watch displays and computer graphics to large area information panels. If two such shutter devices, working in one of the several absorption modes, are combined in a pair of spectacles or goggles such that each device shutters one eye and if a suitable video image is viewed through two such devices driven out-of-phase, the switching speed is such that switching takes place between video frames to that a three dimensional image without flicker may be seen by the observer.

As illustrated in Fig. 1, a single such device can be produced in a conventional glass cell between two sheets 10 of glass which may incorporate transparent electrodes for connection to the power source and which may be provided with or aligning layers 10 or grating surfaces to produce molecular alignment coated thereon. These layers cause the smectic planes to sit perpendicular to the glass substrates and may be used to control tilt at the surface as well as the mean planar direction of order. Between the glass layers 10 is the ferroelectric liquid crystal-containing medium 11 and the whole system may be arranged between crossed polarisers 12 and 13. Suitable spacing material may be included in the device to maintain a well

defined liquid crystal medium thickness. In a simple transmitting shutter device an optional layer 14 could be used as a colour filter to give coloured images or effects, or if the shutter was used in reflection or trans-reflection this layer could be a high reflectivity, coloured or black or white or fluorescent surface to give improved optical contrast and/or brightness. In certain single or zero poloariser devices the layer 14 could be included within the device as shown at 14, or on the electrodes or in the glass substrate.

Transmission of light through the cell occurs in the birefringent mode when the molecular order in the liquid crystal material is not parallel to one of the polariser directions. Absorption or extinction of the light occurs when the molecules are parallel to one of the polariser directions. Switching between these modes occurs in less than 1 ms on application of a voltage pulse at less than 20 volts. Maximum transmission in the birefringent mode is achieved when the molecules are switched through an angle of 45° with respect to the polariser direction. To optimise the contrast ratio between extinction and transmission, suitable black, coloured or fluorescent dyes may also be dissolved in the liquid crystal material.

Single polariser devices may be used as shutters. In such a configuration the absorption moment of the dye

dissolved or included in the liquid crystal medium is aligned co-operatively via the liquid crystal alignment relative to that of the static polariser Fig. 4 illustrates a light absorption condition in which the dye molecules are aligned with the polariser direction, whilst Fig. 4b shows non-absorption with the molecular orders crossed with the polariser direction. The angle θ between the absorption moment of the dye and the polariser direction, defines the degree of light transmission. This is shown in the graph of Fig. 5 giving angle θ against transmitted intensity. In this Guest-Host configuration many of the constraints implicit in the birefringence device are overcome. For example optical defects due to slight misalignment of ferroelectric domains or variations in sample-thickness are much less apparent. In a single polariser configuration such as this, the contrast/brightness ratio can be adjusted by manipulation of the liquid crystal versus polariser angle in the 'off' state. Although, theoretically maximum contrast and brightness is observed for $\theta = 90°$, variation of the polariser angle has allowed acceptable contrast with θ much smaller than this and typically of the order of 45°.

In another embodiment, both polarisers may be omitted and the shutter is produced with two superimposed "layers" of ferroelectric material operating in an absorbing Guest-Host relationship, (described above) one of which effectively takes the place of the static polariser. Fig. 6a illustrates the "off" state whilst Fig.

6b illustrates the "on" or transmitting state. In this arrangement the switching of the shutter can be up to and beyond twice as fast as the birefringent or single polariser cell, using the same liquid crystal materials in the devices, since each dye cell must rotate only half as far for the equivalent optical contrast. In this shutter configuration the maximum theoretical brightness and contrast are obtained when θ is 45° in opposite directions for the two superimposed "layers" thus giving a total angle equivalent to the single polariser device of 90°.

In another embodiment the absorbing dye may be fluorescent or luminescent (Fig. 7). In the case of a single polariser maximum light absorption and intensity is given by the absorption direction being parallel to the input polariser direction (Fig. 7a). The absorbed light is thus re-emitted at a different wavelength in the "on" state (Fig. 7a). In the "off" state the absorption and therefore the re-emitted fluorescent or luminescent light decreases leaving only low intensity residual light transmitted. Thus there is an optical contrast between the two states and the schematic transmission characteristics are given in the graph of Fig. 8. The input polariser may be rotated to reverse the light levels of the two states. Different optical contrasts may be obtained using coloured polarisers or input light filters. For example, a switchable two-colour device is porvided by using a filter of a different

colour from that of the fluorescent dye. With this embodiment, it is possible to produce bright reflective light, for example in direct sunlight, or transmissive displays using suitable background lighting.

In another embodiment a single layer fluorescent Guest-Host device may be constructed without polarisers, Fig. 9. In this case the input light is incident on the cell along (rather than through) the layer direction such that in the "off" state, (Fig. 9a) the input light is along or predominantly along, the direction of the absorption moment so that little or no absorption occurs (Fig. 9a). In the "on" state the dye rotates so that the direction of the input light and the absorption moment is no longer zero whereupon significant absorption and subsequent fluorescence can take place (Fig. 9b). In this embodiment contrast can be achieved using contrasting filters on the background as described above (layer 14 in Fig. 1). In this mode it is also possible to allow a further "on" state to be aligned such that the chiral structure is not suppressed by the field giving a strong absorption and fluorescence due to the precession of the dye absorption axis around the rubbing direction. Application of a field may then produce an "off" state, as in Fig. 9a or an intermediate "on" state as in Fig. 9b giving different optical contrast between the three states.

In another embodment of the invention Fig. 10 an

absorption mode Guest-Host device without polarisers may be used to switch light to a fluorescent mode Guest-Host device. In the "off" state (Fig. 10a) the absorption direction of the 'absorbing' first cell and the absorption direction of the second or fluorescent cell are parallel giving a dark or weakly coloured state. In the "on" state (Fig. 10b) the angle between the two absorption moments is other than zero up to 90° to give a bright fluorescent state. As in the double absorbing mode device, Fig. 6, no polarisers are required and the optimum light level occurs for each cell moving through 45°. Response times may be at least twice as fast as for each individual Guest-Host device.

In yet another embodiment of the invention, (Fig. 11) a different surface alignment agent may be used to give "homeotropic" alignment. In this case the smectic planes lie parallel to the substrate. The tight helical pitch, necessary in this case, causes the molecules to be directed around in a helix in the direction of propagation of the input light. If the dye included is absorbing, the device appears dark due to the absorption of the unpolarised input light. If a fluorescent dye is included the device appears bright through the absorption/re-emission process described above. Application of an electric field along the plane of the cell (i.e. transverse) with electrodes between the inner and outer substrates re-orders the dyes to decrease

the absorption or fluorescence. If a polariser is included and aligned relative to the dye absorption directions the contrast may be optimised in either case by defining the polariser direction. In this embodiment the device may be used in transmission or reflection or with coloured filters or coloured polarisers as before. In certain other applications the electrode geometry of Fig. 1 could be used with the alignment described in this embodiment.

In the various embodiments described above it is possible to produce optical grey scales by altering the frequency of the various switched states within the integration time of the eye. Thus a dark state could be perceived more often than a light state to give an intermediate grey colour. Simply changing the ratio of "on" to "off" times changes the intensity of the grey scale. When the "on" and "off" states have different colours, shades of colour and composite colours may be achieved using various primary colour filters, dyes or coloured polarisers, by again varying the ratio of "on" to "off" times. In this way all of the colours of the spectrum may be produced.

By selection of the liquid crystal composition and dyes it is possible to optimise the device according to operational requirements, giving preference to switching speed, low driving voltage or high extinction contrast ratios. With these requirements in mind any of the known

ferroelectric liquid crystal phases may be used (eg. S_C^*, S_I^*, S_J^*, S_G^*, etc).

Any constituent of the liquid crystal mixture may incorporate more than one type of functionality. For example, the liquid crystal material may be a dye, a ferroelectric dye, or the dye may be heliochromic thereby inducing a chiral phase. These constituents may be low molar mass or polymeric in nature. In the case of polymer liquid crystals, more than one functionality may be included in any one polymer molecule. The dye may be dichroic, pleochroic, fluorescent, or optically non-linear. In the case of dichroic or pleochroic dyes they may absorb any colour or combinations of colour to appear monochromatic polychromatic or black.

The ferroelectric liquid crystals may be microencapsulated or dispersed in voids in a polymer or glass matrix contained between the electrodes and substrates. Conventional micro-encapsulation or dispersion techniques or photo-etching of a suitable polymer may be used to produce these voids. In the case of micro-encapsulation or dispersion the voids may be configured to produce preferential alignments. In the photo-etch process surface alignment techniques known to those skilled in the art may be used. The glass substrates on which the electrodes are deposited could equally well be of plastics

and may be coloured. In this way light weight flexible displays or shutters may be produced. In the embodiments incorporating a polariser one or both of the substrates containing the ferroelectric material may be the polariser.

Further for 3-D viewing the shutters may be presented in the form of standard plastics or glass spectacles. The supporting matrix may be preformed or moulded as required for specific optical components. In a 3-D imaging application or indeed in the other embodiments, two possibilities exist for switching the shutters off for the observer to view normally. Firstly, if the shutters are used in a bistable configuration where the pitch of the Chiral Smectic C phase is greater than the thickness of the liquid crystal layer, the shutter glasses may be used to observe conventional images by simply switching both shutters to the transmitting state and removing the driving voltage.

Alternatively, if the shutter glasses are to be used in the non-bistable configuration, conventional viewing can be obtained either by leaving a driving voltage on both cells in the transmitting state or by removing the voltage from both cells such that relaxation of the molecules gives an intermediate state through which an acceptable amount of light may be transmitted. Liquid crystal shutters made in this way may be used with an X-ray imaging device in which an infra red pulse from a video

display unit synchronises the switching of the driving pulses. Alternatively, synchronisation may be achieved electronically or optically or by other means.

By using suitable electrode patterns and materials, a video image itself may be projected directly to glasses worn by the observer. In this case, synchronisation could be via an infra red signal from a raster on a blank screen, or electronically or optically. In such an arrangement the observed image could be unique for each of a number of observers so that several people in the same room could watch different three dimensional video programs.

For display applications conventional electrode arrangements such as alpha-numeric, dot matrix and meander patterns may be used on either the glass or polymer substrates. Thus the displays could be flexible and light weight. These would have numerous applications in the automotive, aeronautic, naval and space industries where high speed and low weight are important.

The shutters could equally well be used as fast electro-optic light modulators with applications in pattern recognition fibre optics and "Q" switch elements for laser cavities and non-linear optics.

It is not intended to limit the invention to the above examples only, many variations such as might readily occur to persons skilled in this art, being possible without departing from the scope of the invention, as defined in the appended claims.

A wide range of ferroelectric liquid crystals have been examined for use in the Guest-Host devices described above. Typical ferroelectric host materials used have been based on chiral fluoro-esters, phenylpyrimidines, and phenylpyridines amongst others. Chiral and non chiral dyes based on pirylenes and anthraquinones have been used along with azo and mixtures of anthraquinone dyes to produce coloured and black dye compositions. As well as the fluorescent pirylene materials dinitrostilbene has been used in fabrication of the devices. These structures are not limiting, and any material that exhibits ferroeletric phases and the optical effects described would be suitable provided that the absorption or absorption and emission directions are altered on application of an electric field.

CLAIMS

1. A liquid crystal device which may be operated selectively to transmit or absorb light, incorporating a ferroelectric liquid crystal phase as exhibited by low molar mass or polymeric compounds or mixtures thereof.

2. A liquid crystal device according to Claim 1, wherein said ferro-electric phase is a Chiral Smectic phase.

3. A liquid crystal device according to Claim 1 or Claim 2, in which the device changes from a light-transmitting to a light-absorbing state, or vice versa, in a period of less than 1 millisecond with the application of a driving field of 20 volts per micron or less.

4. A liquid crystal device according to any preceding claim, wherein the ferroelectric material is disposed between two sheets of a substrate material at least one of which is transparent, and incorporating electrodes for connection to a power source.

5. A liquid crystal device according to Claim 4, wherein said substrates are coated with aligning layers or grating surfaces to produce molecular alignment.

6. A liquid crystal device according to any preceding

claim, including, in the light path thereto, a polariser.

7. A liquid crystal device according to any preceding claim, including, in the light path, a coloured filter or coloured reflective or trans-reflective surface, to produce or enhance coloured images or effects.

8. A liquid crystal device according to any preceding claim, wherein the ferroelectric material is constituted by or contains a dye.

9. A liquid crystal device according to Claim 8, wherein said dye is dichroic or pleochroic.

10. A liquid crystal device according to Claim 8, wherein said dye is fluorescent or luminescent.

11. A liquid crystal device according to any one of Claims 1 to 9, incorporating a single polariser, and an absorbing dye as or within the ferroelectric material.

12. A liquid crystal device according to any one of Claims 1 to 9, including two superimposed layers of ferroelectric material operating in an absorbing Guest-Host relationship without polarisers, such an arrangement providing a faster switching speed when compared with a single layer of material combined with a static polariser.

13. A liquid crystal device according to any one of Claims 1 to 8, including one layer of ferroelectric material containing a fluorescent dye, and superimposed with a single polariser, such that maximum light absorption and intensity is given by the absorption direction being arranged parallel to the input polariser direction whilst misalignment of the dye molecules with the polariser direction minimises light absorption and re-emission.

14. A liquid crystal device according to any one of Claims 1 to 5 or Claim 7, including two superimposed layers of ferro-electric material operating respectively in absorbing and fluorescent Guest-Host relationships such that the material operating in the absorbing mode serves, by molecular alignment, to switch the material operating in the fluorescent mode between absorption and non-absorption.

15. A liquid crystal device according to any one of Claims 1 to 5 or Claim 7, comprising a single layer fluorescent Guest-Host device adapted to receive input light incident upon the layer along (rather than through) the plane thereof.

16. A liquid crystal device according to Claim 1, wherein an electric field is applied along (rather than through) the plane of the device using transverse electrodes co-operating and placed between two substrates

at least one of which is transparent, and enclosing the ferroelectric material.

17. A liquid crystal device according to any preceding claim, including means to modulate the frequency of an applied alternating field within the integration time of the eye thus to enable different colours and grey scales to be created.

18. A liquid crystal device according to any preceding claim, wherein the ferroelectric material is micro-encapsulated.

19. A liquid crystal device according to any preceding claim, wherein said ferroelectric material is dispersed within voids in a polymer or glass matrix contained between a pair of electrodes.

20. A liquid crystal device according to Claim 19, wherein the voids are configured to produce preferential alignment.

21. A liquid crystal device according to any preceding claim, wherein two such devices are provided in the form of a pair of spectacles to be worn by an observer, and means for switching the two devices alternately thus to produce a three-dimensional effect, further means being provided to

switch the devices to remove the effect thus to return to normal viewing.

22. A liquid crystal device according to any preceding claim, wherein the ferroelectric material is adapted for operation selectively at normal ambient temperatures or at other temperature levels.

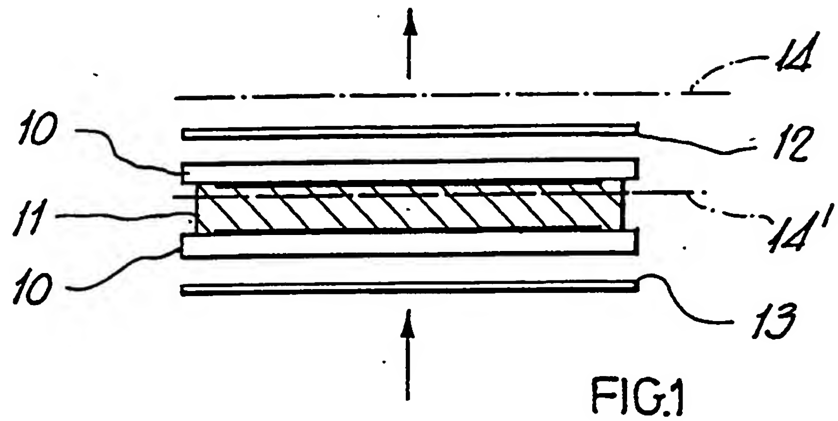

FIG.1

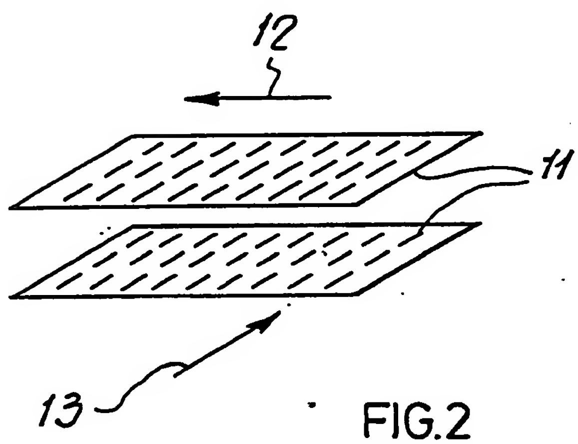

FIG.2

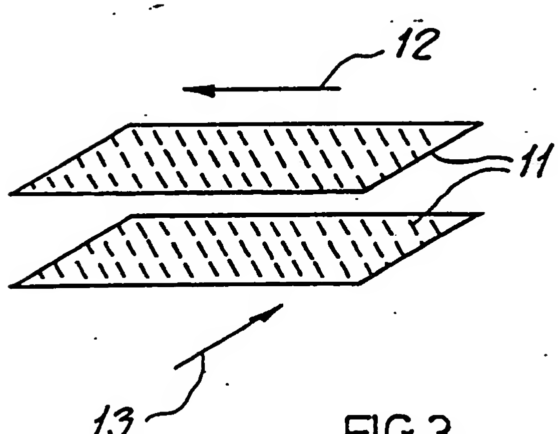

FIG.3

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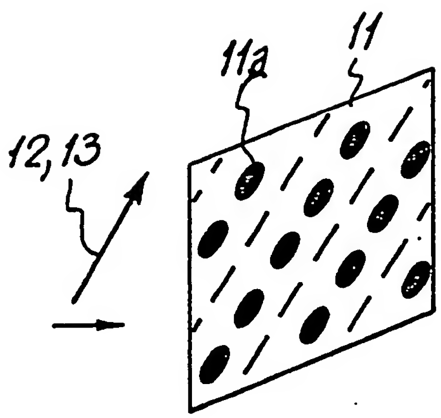

FIG.4a

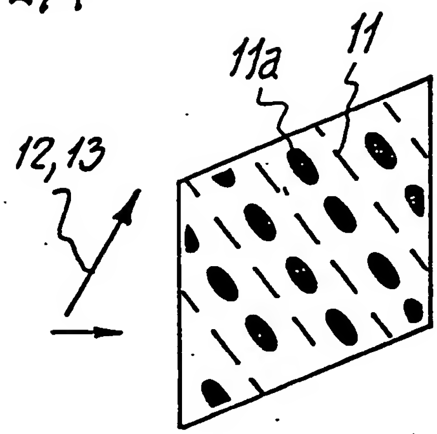

FIG.4b

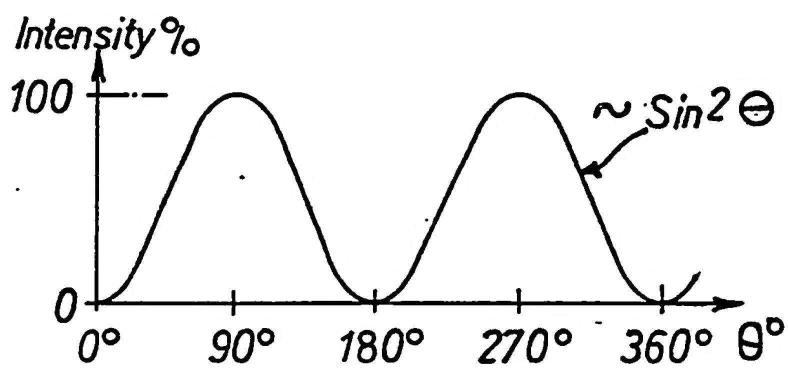

FIG. 5

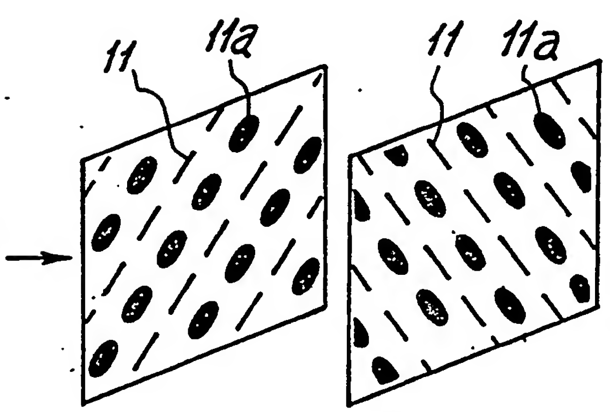

FIG.6a

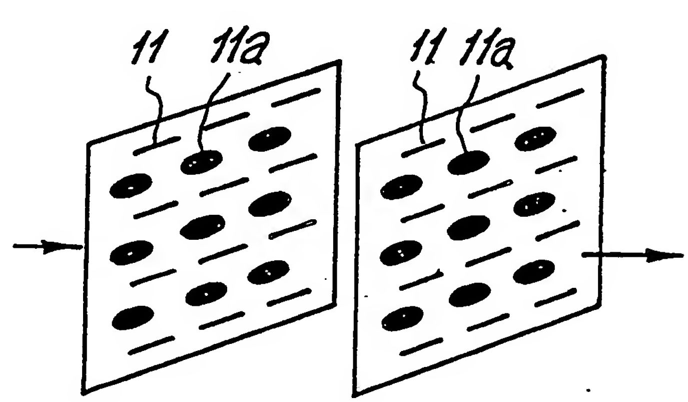

FIG.6b

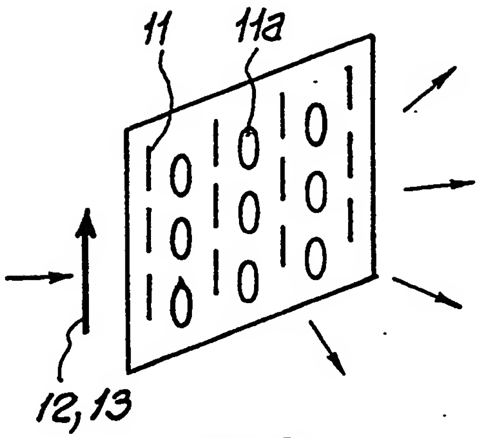

FIG.7a

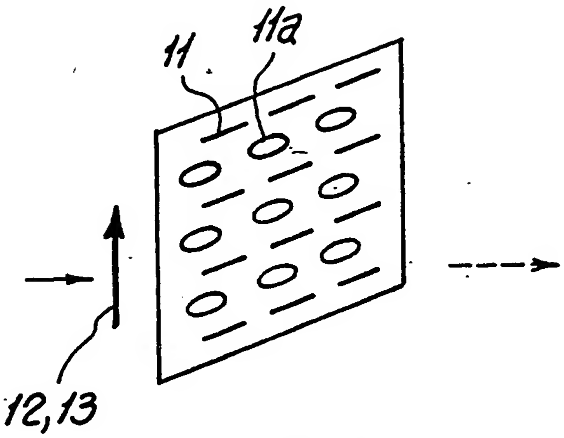

FIG.7b

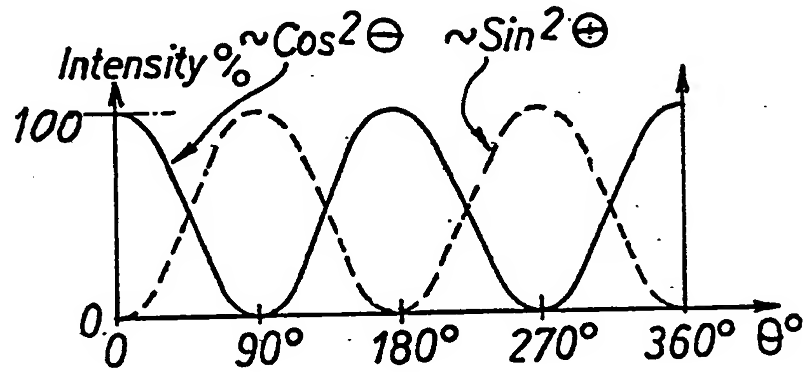

FIG.8

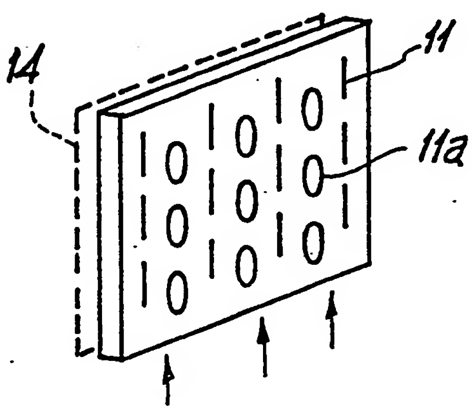

FIG.9a

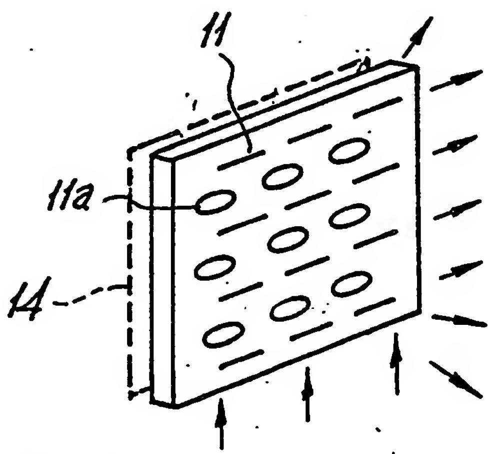

FIG.9b

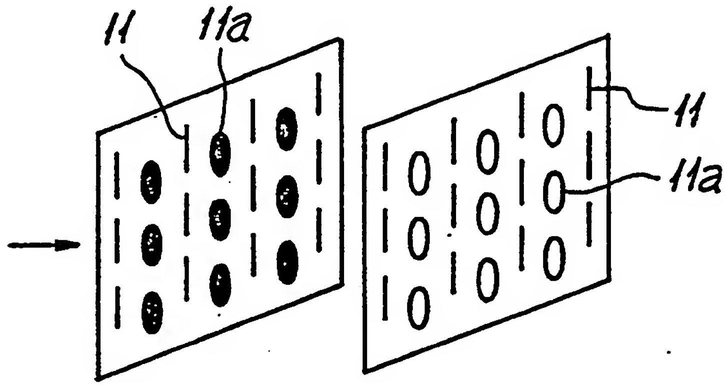

FIG.10a

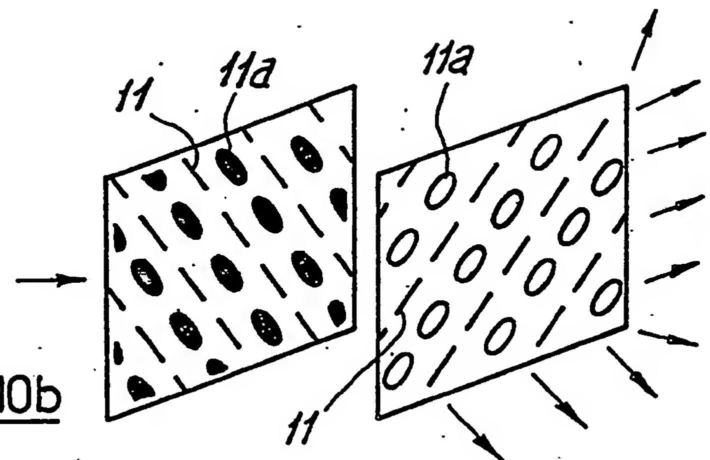

FIG.10b

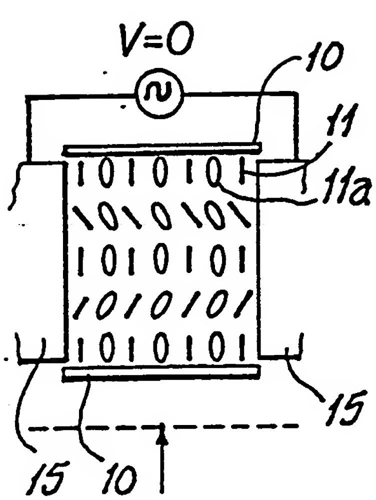

FIG.11a

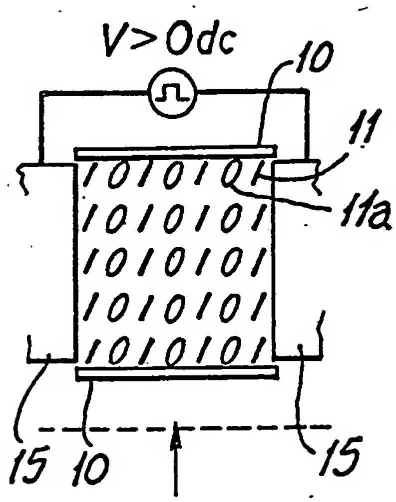

FIG.11b

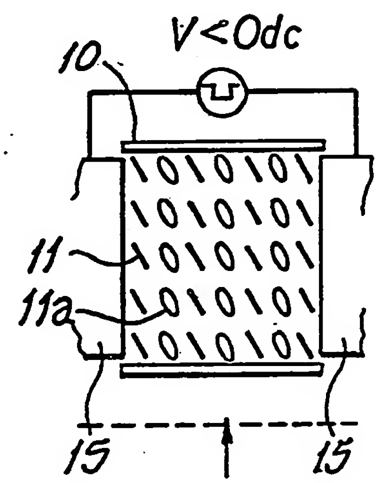

FIG.11c

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 88/00320

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: G 02 F 1/137

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	G 02 F 1/00; C 09 K 19/38

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
X	WO, A, 86/06507 (ATT) 6 November 1986, see page 10, line 12 - page 11, line 21; page 16, lines 20-32	1-6
Y		6-9,11,12, 22
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* Special categories of cited documents: [10]
"A" document defining the general state of the art which is not considered to be of particular relevance
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
28th July 1988	26 AUG 1988
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	P.C.G VAN DER PUTTEN

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
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SA 22034

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 11/08/88
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